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Palynology of the Eocene-Oligocene transition in the marginal zone of the Magura Nappe at Folusz (Western Carpathians, Poland)

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Abstract: Palynological investigations of the deep-marine Upper Eocene–Lower Oligocene, mainly turbiditic and hemipelagic sediments exposed at Folusz (Siary Zone of Magura Nappe, Polish part of the Western Carpathians), revealed a prevalence of land plant remains in the palynofacies. Dinoflagellate cysts are the most frequent among marine palynomorphs. A Priabonian age is found in the lower part of the Szymbark Shale; a Rupelian age is determined for the investigated part of the Magura Beds. Dinoflagellate cyst distribution shows no major changes, contrary to an outstanding change recorded in the coeval sediments from other parts of the Polish Carpathians. This implies different paleoenvironmental conditions in the northern part of the Magura Basin during the latest Eocene and Early Oligocene. Occurrence of high-latitude dinoflagellate cysts in the lowermost part of the section may be related to a drop of temperature in the surface waters of the sedimentary basin during the Late Eocene. Dinoflagellate cysts, whose motile stages are thought to have inhabited near-shore waters, are frequent in turbidites, whereas the hemipelagic/pelagic sediments usually contain more numerous oceanic specimens. Recycled dinoflagellate cysts occur more frequently in turbidite sediments.

Key words: Carpathians, Eocene-Oligocene transition, Magura Nappe, paleoenvironment, biostratigraphy, flysch deposits, dinocysts.

Introduction

The Eocene-Oligocene transition in the northern part of the Magura Nappe (Siary Zone *sensu* Koszarski et al. 1974) of the Polish Carpathians is represented by a rock succession different from coeval successions of the other parts of the Polish Outer Carpathians. Except for some localities in the eastern sector of the Siary Zone, the succession consists mainly of thick-bedded (0.5 to a few meters) turbidites with variable sandstone to shale ratio, distinguished as the Magura Beds (Szajnocha 1895; Świdziński 1934). In some places, in the marginal part of the eastern sector of the Siary Zone, including the Folusz area (Fig. 1), the Priabonian consists nearly exclusively of fine-grained sediments of turbiditic and hemipelagic origin, distinguished by Kopciowski (1996) as the Szymbark Shale and included in the Zembrzyce Shale by Oszczypko-Clowes (2001). Age-assessments based on foraminifers indicate that the lower boundary of typical Magura Beds (see Książkiewicz 1974) is here located close to the Eocene-Oligocene boundary (Blaicher & Sikora 1963; Sikora 1970; Leszczyński & Malata 2002). At the same time, in the major part of the inner zones of the Magura Nappe, this succession is restricted to the Eocene (Oszczypko-Clowes 2001).

In the other parts of the Polish Outer Carpathians, the Eocene-Oligocene transition is represented by a several meters thick package of *Globigerina*-rich marlstones, distinguished as the Sub-Menilite Globigerina Marl (Koszarski & Wieser 1960). The lower part of the overlying unit, known as the Menilite Beds, is dominated by black, organic-rich fine-grained sediments. Similar sediments are also known from some areas in the southernmost part of the Magura Nappe. The package of marls rich in *Globigerina* is distinguished there as the Leluchów Marl Member, whereas the unit corresponding to the Menilite Beds is called the Smereczek Shale Member (Birkenmajer & Oszczypko 1989). The so developed Eocene-Oligocene transition displays a major turnover in microfossil assemblages. Rich and diversified Late Eocene foraminifers, calcareous nannoplankton and dinoflagellate cyst assemblages become significantly impoverished in the earliest Oligocene (e.g. Olszewska 1984, 1985; Van Couvering et al. 1981; Gedl 1999). Analysis of organic-walled dinoflagellate cysts (hereafter dinocysts) from these sediments implies that significant paleogeographical and paleoenvironmental changes occurred, including a drop in sea surface temperature and salinity decrease within the photic zone. This paper aims at describing and interpreting the palynological record of the Eocene-Oligocene transition in one section from the northern part of the Magura Nappe, outstanding for its distinctive lithological development. Interpretation of the results is compared with the results of palynological studies of coeval sediments characterized by a markedly different development.

Section location and stratigraphy

A 114 m thick succession representing the Szymbark Shale and the lower part of the Magura Beds, exposed in the bed of Kłopotnica Stream in the village of Folusz was selected for the

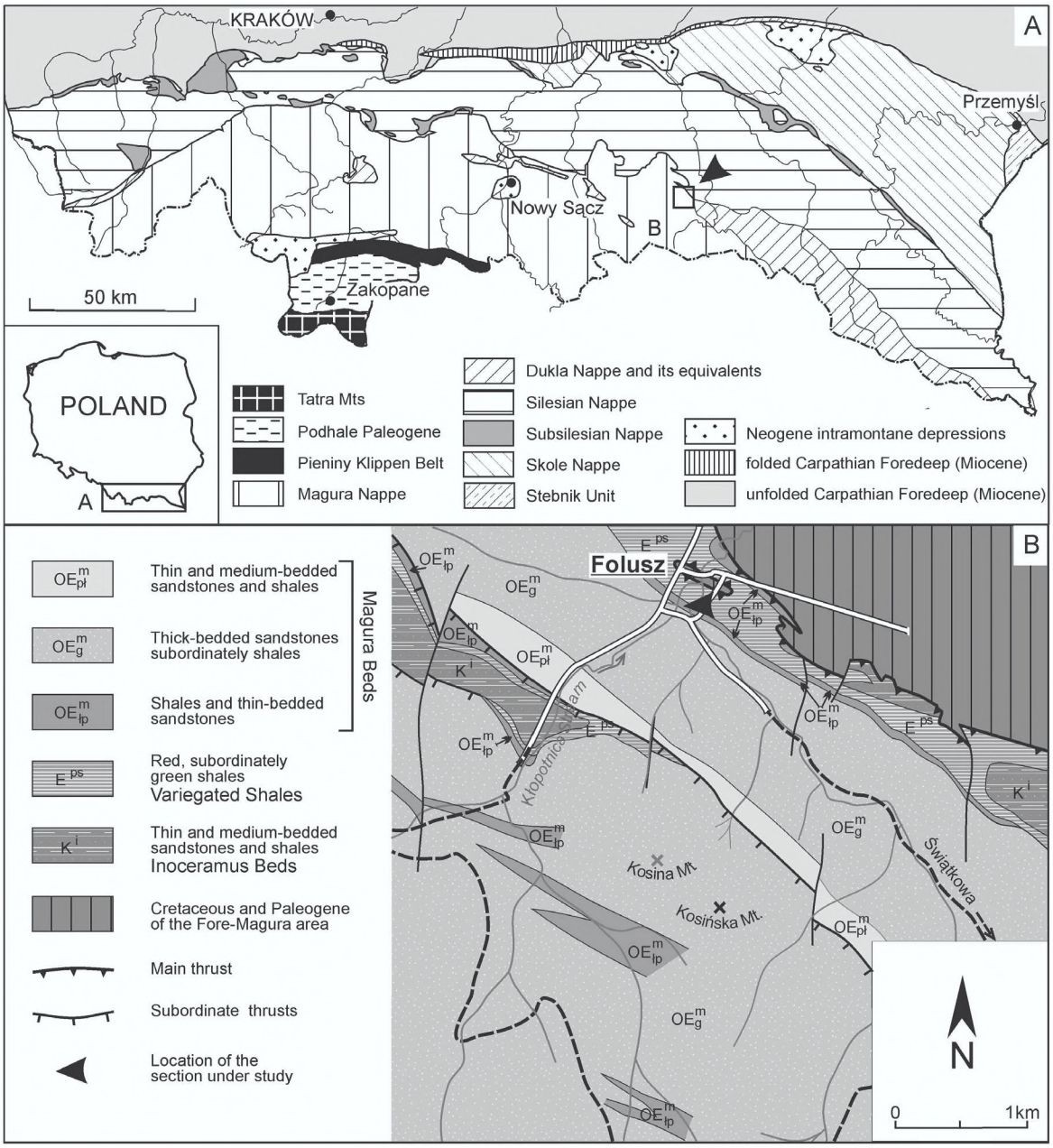


Fig. 1. Location of the studied section (arrowed): **A** — according to tectonic map of the Polish Carpathians after Książkiewicz (1977); **B** — according to geological map after Koszarski & Tokarski (1968). Unit marked OE^{m}_{lp} in northern outcropping zone includes the Szymbark Shale.

present study (Fig. 1). This section is one of the best-exposed sections of the basal part of the Magura Beds and their immediate substrate in the frontal part of the Magura Nappe (Fig. 1A). This section is also best recognized in the sense of litho- and biostratigraphy (see Sikora 1970; Oszczypko-Clowes 2001; Leszczyński & Malata 2002). Moreover, tuffite recorded here was dated radiometrically (Van Couvering et al. 1981).

The Folusz section is located in the central part of the Polish Carpathians, at the northern foots of the Magura Wątkowska Range in the Beskid Niski Mountains. The section starts at the upper boundary of the red shale succession (Łabowa Shale Formation *sensu* Oszczypko 1991) and extends up the stream, up to the bridge of a local road toward the village of Świątkowa (Fig. 1B). The lower part of the section, approximately 36 meters thick, called by Kopciowski (1996) the Szymbark Shale, consists basically of alternating thin layers of light green to dark green, occasionally black and dark brown muddy to clayey, calcareous to non-calcareous shales (Fig. 2). The proportion of calcareous and dark coloured shales increases up section. Moreover, several thin siltstone and fine-grained sandstone beds, and one 4 cm thick layer of bentonitic tuffite occur in this unit. The position of the tuffite in the section (Fig. 2), together with its thickness and colour, suggest that this is the tuffite mentioned earlier by Sikora (1970). Zircons from this layer were dated by fission-track analysis at 32.8±1.3 Ma (Van Couvering et al. 1981), i.e. close to the

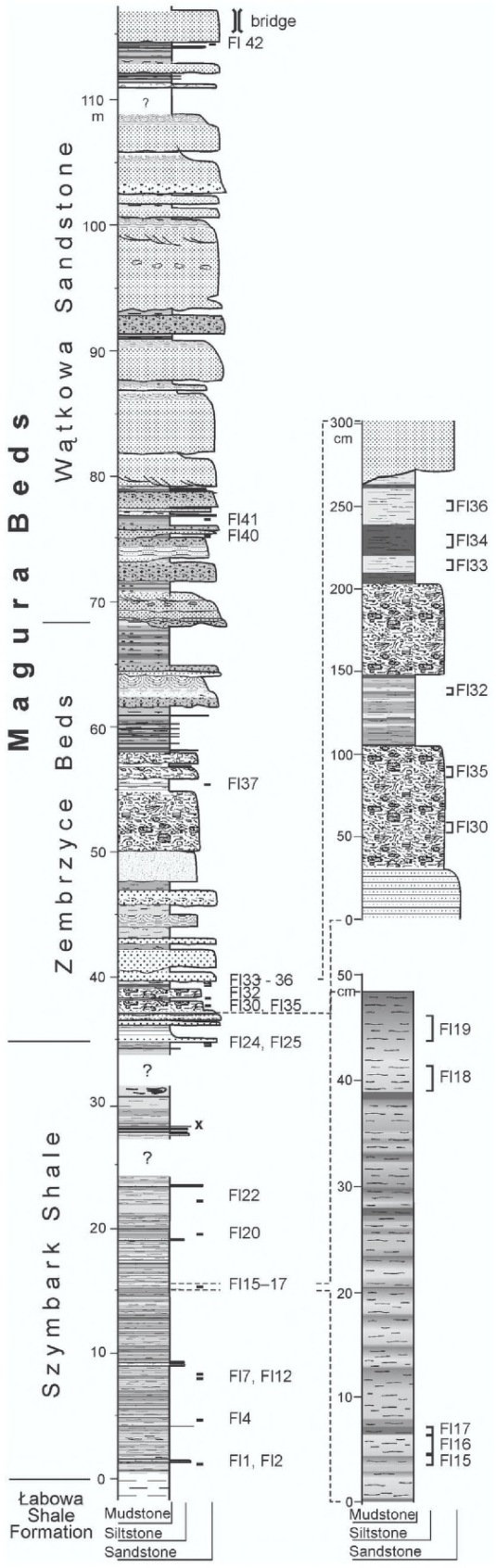


Fig. 2. Vertical lithofacies logs and lithostratigraphy of the studied section at Folusz, and sample locations (cf. Leszczyński & Malata 2002).

Eocene-Oligocene boundary (33.7 Ma according to Berggren et al. 1995). In the upper part of this unit, Blaicher & Sikora (1963) found a foraminiferal assemblage corresponding to that recorded in the Sub-Menilite Globigerina Marl (upper part of Upper Eocene) of the outer flysch nappes. These authors called this interval "Marls with Globigerina" (cf. Sikora 1970). The calcareous nannoplankton Zone NP19–20 (Martini 1971) was recognized in the lower part of the Szymbark Shale, and Zone NP21 in its upper part, ca. 11 m above the base of the unit in Oszczypko-Clowes (2001), or 17.0 m in Leszczyński & Malata (2002).

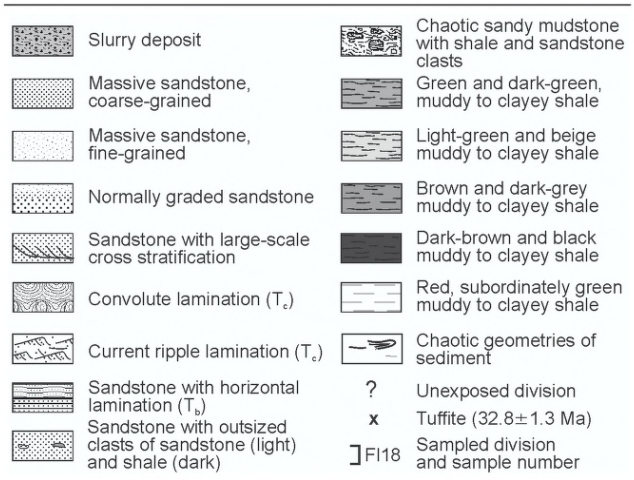
The overlying 33 m thick succession is built of thin to thick-bedded fine to very coarse-grained sandstones, chaotic sandy-mudstones and thick to thin layers of calcareous to non-calcareous mudstones (Fig. 2). This unit is called here the Zembrzyce Beds, and considered to be the basal part of the Magura Beds. Calcareous nannoplankton investigations indicate that the entire unit is enclosed within Zone NP21.

Very thick-bedded coarse- to fine-grained sandstones and granule-conglomerates dominate in the remaining part of the section (Fig. 2). This part of the section is considered as the Wątkowa Sandstone *sensu* Koszarski (1976). It represents the higher part of the Magura Beds. The base of calcareous nannoplankton Zone NP22 was identified in the top part of the section (Oszczypko-Clowes 2001).

Materials

Twenty-one samples from surface outcrops in the Kłopotnica Stream were investigated in this study. These samples were selected from those taken earlier for other sedimentological and stratigraphical investigations (Leszczyński & Malata 2002).

Eleven samples (Fl1–Fl25) represent the Szymbark Shale, seven samples (Fl30–Fl37) were taken from the Zembrzyce Beds, and three (Fl40–Fl42) from the Wątkowa Sandstone (Fig. 2). All samples except for the Fl30 and Fl35 were taken from muddy to clayey shales. Their location in the sequence as well as foraminiferal content and composition suggest



Legend to the Fig. 2.

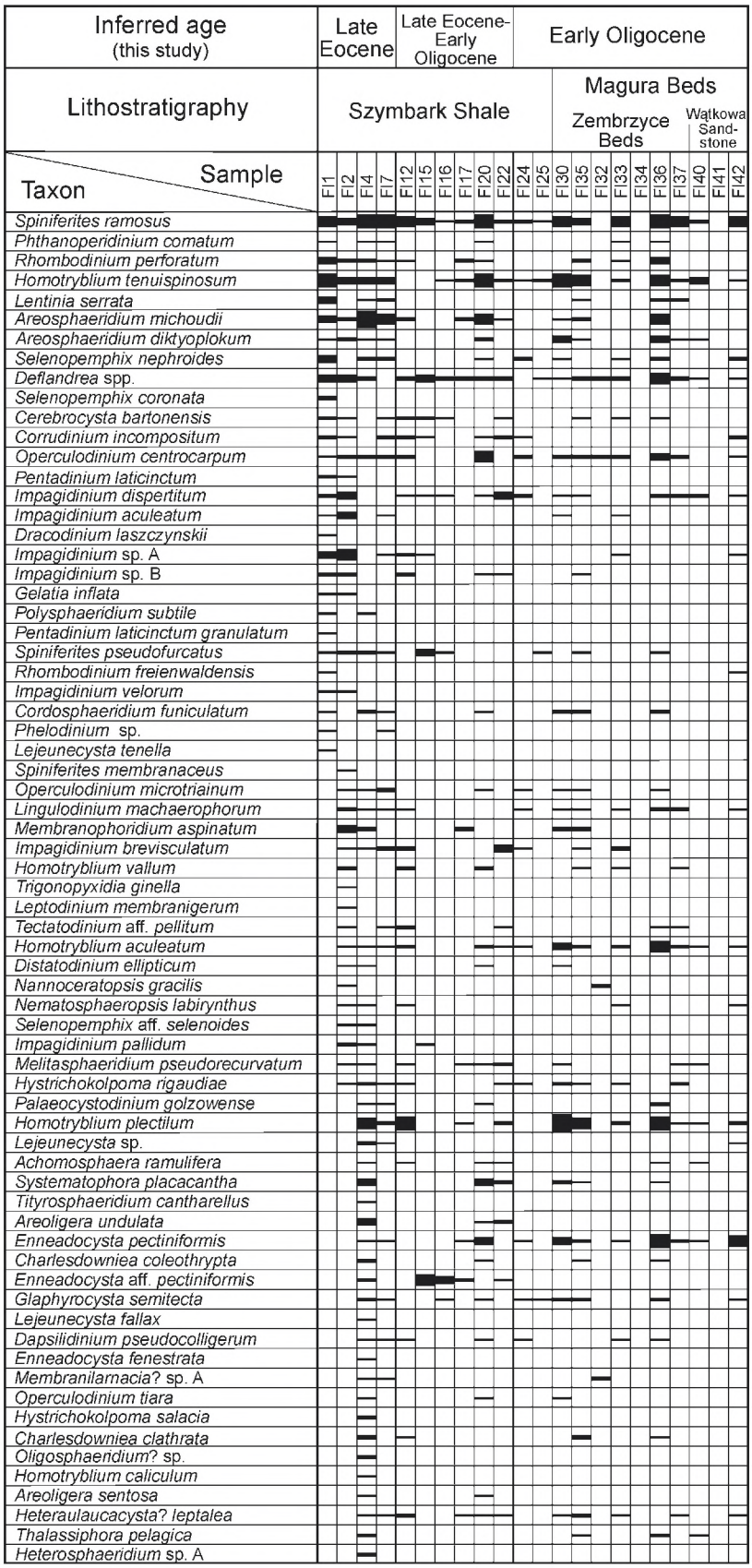


Fig. 3. Range chart of dinocysts from Folusz section. Line widths reflect number of specimens counted. Continued on the page 159.

hemipelagic and/or turbiditic origin (Table 1; Leszczyński & Malata 2002). The samples Fl30 and Fl35 were taken from a chaotic sandy-mudstone breccia. This is a sediment consisting of a sandy calcareous mudstone (marlstone) matrix with quartz grains as much as 7 mm in cross-section and chaotically distributed dark green, brownish and grey, sharp-edged mudstone chips and larger clasts. These features indicate deposition by debris flow mechanisms.

Methods

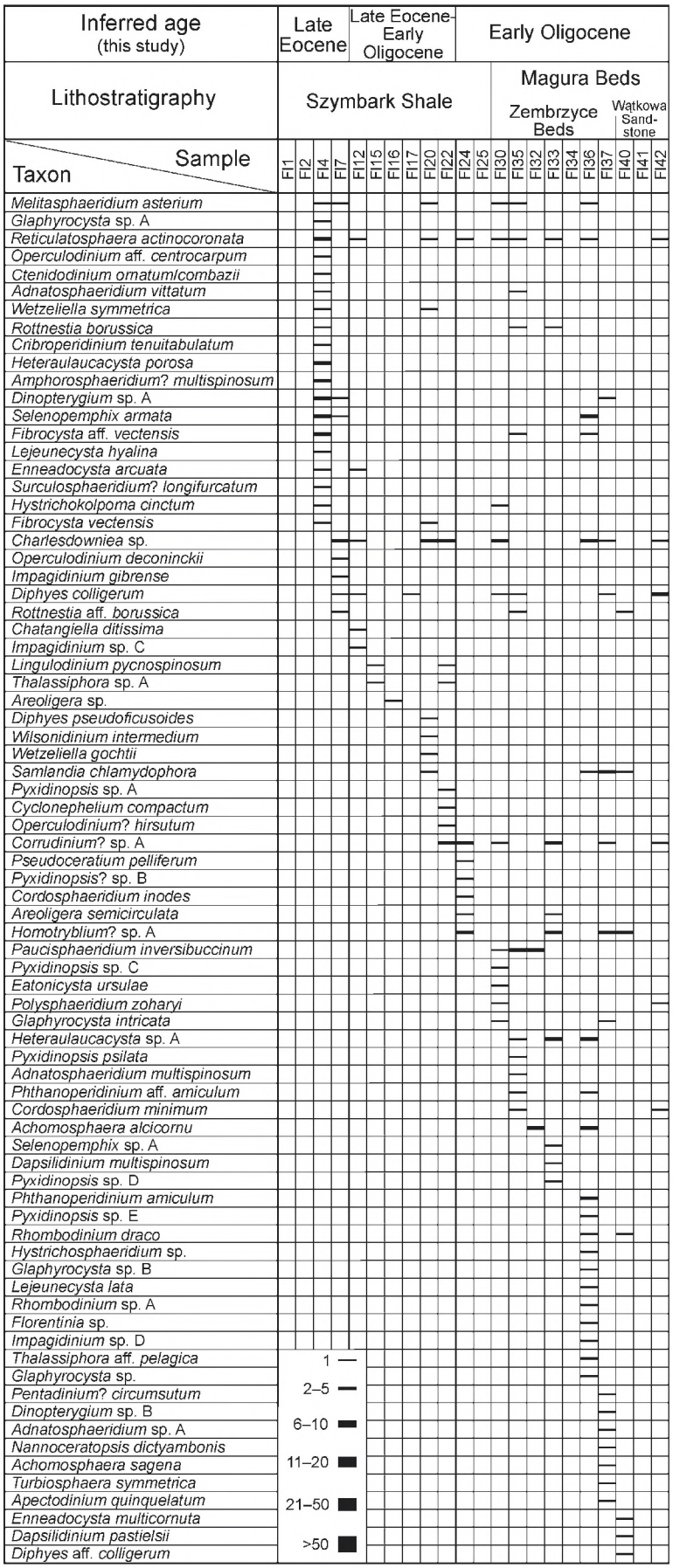
The samples were processed following standard palynological procedure, including 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$+HCl; density 2.0 g/cm^3) separation, ultrasound for 10–15 sec., and sieving at 15 μm on a nylon mesh. The samples were processed in the Micropaleontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. The quantity of rock processed varied from 20 to 30 g. Two microscope slides were made from each sample using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

All dinocysts were counted from one of two slides. The second slide was scanned for additional dinocyst taxa. Slides were examined under the transmitted light microscope Carl Zeiss Axiolab. Microphotographs were taken with the Sony DSC-S75 camera and Zeiss Plan-Neofluar 100 ×/1.30 Oil Pol objective.

Results

All samples contain organic particles of a diameter greater than 15 μm. The majority of these particles represent land plant remains. They include cuticle with variously preserved tissue structures, dark brown equidimensional particles with slightly transparent edges and opaque, small-sized, woody particles. Sporomorphs (mostly the bisaccate pollen grains) occur subordinately. Amorphous organic matter occurs in trace amounts only.

Marine palynomorphs, rarely exceeding 1–2 % of the palynofacies, are represented primarily by dinocysts (Figs. 3, 4). Acritarchs and foraminiferal linings occur occasionally. The highest amount of dinocysts, reaching 8 % of the palynofacies, is recorded in sam-



ples Fl4 and Fl7, representing the Szymbark Shale. Samples Fl34 and Fl41 (the Zembrzyce Beds and the Wątkowa Sandstone respectively) do not contain dinocysts or contain only a few indeterminable specimens. Acritarchs occur mainly in the lower part of the Szymbark Shale (samples Fl1–Fl7), being the most frequent in sample Fl4. They represent morphotypes of *Veryhachium* affinity. Microforaminifers (mainly trochospiral and planispiral morphotypes) are very rare within the whole section except for the sample Fl4 where they are relatively frequent.

The dinocyst distribution shows distinct relation to the sediment origin (Fig. 5). Samples taken from turbidites and mud-flow deposits (Table 1) are either devoid of oceanic dinocysts (e.g. *Impagidinium* spp.; see e.g. Dale 1996), or they occur there as single specimens only. Specimens of *Impagidinium* (Fig. 4.3,6,8,13) are much more frequent in samples representing hemipelagites (Table 1). In these samples, *Impagidinium* constitutes up to 30 % of all dinocysts (sample Fl22). The samples taken from turbidites, in turn, contain high numbers of *Homotryblium* spp., a genus related by several authors to inshore, lagoonal settings (e.g. Brinkhuis 1994).

Dinocyst stratigraphy of the Folusz section

The occurrence of calcareous foraminifers and nannoplankton in the studied succession mainly in resedimented deposits (see Leszczyński & Malata 2002) hampers a precise interpretation of stratigraphy based on these fossils. Recycling also concerns dinocysts as has been shown in these investigations. However, dinocysts also occur in background sediments (hemipelagites) where they appear to be synsedimentary. Reworking makes particularly tentative the identification of biozones or events defined according to the highest occurrences of fossils, for example the NP21 and the NP22 Calcareous Nannoplankton Zones of Martini (1971).

Location of the Eocene-Oligocene boundary in the investigated section has not been precisely established during this study. The Early Oligocene has been definitely determined for the section division located above sample Fl24 (the topmost part of the Szymbark Shale) where *Areoligera? semicirculata* (Fig. 4.2) has its lowest occurrence (Fig. 6). This species is known to have its first appearance in the earliest Oligocene (e.g. Morgenroth 1966; Brinkhuis 1994), Rupelian (Stover & Hardenbol 1993; Stover et al. 1996) or Chattian (Powell 1992). This agrees with the age 32.8±1.3 Ma, obtained by Van Couvering et al. (1981) from radiometric dating of the tuffite found approximately 7 m below the sample Fl24. The age of the Magura Beds, overlying the Szym-

Table 1: Selected sedimentological and geochemical features of the sampled sediments.

Sample No.	Sediment colour	Reaction with HCl	Bed thickness [cm]	$CaCO_3$ [%]	TOC [%]	Sand fraction			Sediment origin
						Detritus %	Foraminifera number		
							Agglut.	Calc.	
Fl1	dark brown	+	3.0	nd	nd	nd	nd	nd	Hemipelagite?
Fl2	green	–	8.0	nd	nd	nd	nd	nd	Hemipelagite?
Fl4	brown-grey	+	5.0	17.70	0.46	0.175	572	3256	Turbidite
Fl7	brown	+	16.0	21.98	0.50	s	3	43	Hemipelagite?
Fl12	green	–	15.0	0.42	0.18	s	678	1	Hemipelagite
Fl15	green	–	1.0	nd	nd	s	3208	128	Hemipelagite?
Fl16	beige	+	2.0	10.25	0.30	s	504	48	Hemipelagite?
Fl17	dark brown	–	0.7	1.17	1.74	tr	200	18	Hemipelagite?
Fl20	brown	+	27.0	18.67	0.55	–	1	2	Turbidite
Fl22	beige and green	+, –	30.0	6.17	0.28	tr	1132	16	Hemipelagite?
Fl24	grey-green	+	>20	nd	nd	~5.0	44	1190	Turbidite/Hemipelagite
Fl25	dark brown	–	7.0	0.33	3.20	9.5	64	32	Turbidite
Fl30	green/dark grey	+	75.0	nd	nd	~12.0	400	20868	Mud-flow deposit
Fl32	green/dark grey	–, (+)	40.0	nd	nd		68	56	Turbidite/Hemipelagite
Fl33	grey	–	10.0	nd	nd	tr	22	–	Hemipelagite?
Fl34	dark brown	–	19.0	nd	nd	tr	–	–	Turbidite
Fl35	grey/green	+	75.0	nd	nd	~15.0	nd	nd	Mud-flow deposit
Fl36	grey-green	–, (+)	22.0	nd	nd	tr	8	32	Turbidite/Hemipelagite
Fl37	grey	+	10.0	nd	nd	tr	22	8	Turbidite
Fl40	grey-green	+	7.0	nd	nd	nd	nd	nd	Turbidite?
Fl41	black	–	7.0	nd	nd	nd	nd	nd	Hemipelagite?
Fl42	grey	+	6.0	nd	nd	nd	nd	nd	Turbidite?

Number of foraminiferal specimens calculated for 200 g of dry rock. See Fig. 2 for sample location. Explanation of symbols: + — effervescent reaction with diluted HCl; (+) — weak effervescence; – — lack of effervescence; **tr** — <0.1 %; **s** — several grains; **nd** — not determined.

bark Shale, can be estimated on the basis of superposition only. No typical Oligocene dinocysts like *Wetzeliella gochtii*, *Areoligera*? *semicirculata* or *Chiropteridium lobospinosum* have been found here. The lack of the latter mentioned species may suggest an age not younger than NP23. Powell (1992) and Wilpshaar et al. (1996) recorded the lowest occurrence of *Chiropteridium lobospinosum* within this zone. This species was found in the Polish Carpathians in the Lower Oligocene of the Podhale Flysch (Gedl 2000) and in the Oligocene Krosno Beds, whereas it was not found so far in the lowermost Oligocene in the Menilite Beds (P. Gedl unpubl.).

Other dinocyst events, which may point at the Oligocene age, are rather disputable. One specimen of *Wetzeliella gochtii* (Fig. 4.20) has been found in sample Fl20 (Fig. 6). The lowest occurrence of this species is often accepted as an indicator of the Lower Oligocene (e.g. Costa & Downie 1976; Gruas-Cavagnetto & Barbin 1988), although some authors claimed that this species appeared in the Late Eocene (Châteauneuf 1980; El-Beialy 1988). In the Polish Carpathians, specimens of *Wetzeliella gochtii* have been found in higher part of the Sub-Menilite Globigerina Marl at Krosno and Znamirowice (Bujak *in* Van Couvering 1981) or its equivalent at Leluchów (Gedl 2004). In the latter case, the lowest occurrence of *Wetzeliella gochtii* comes from a sample where *Areosphaeridium diktyoplokum* has its highest occurrence.

The lowest occurrence of *Reticulatosphaera actinocoronata* (Fig. 4.15), a species believed to have appeared for the first time in the Oligocene in the middle latitudes (e.g. Manum et al. 1989), was recorded in the Priabonian part of the Szymbark Shale (sample Fl4). On the other hand, Brinkhuis (1994) demonstrated the first appearance of this species in central and northern Italy in the Late Eocene (basal part of the NP21 Zone). An even younger first appearance, early Late Eocene, was recorded by Coccioni et al. (2000) in central Italy. This event was correlated with subChron16n and calcareous nannoplankton Zone NP19/20. The lowest occurrence of *Reticulatosphaera actinocoronata* in the Folusz section can also be correlated with the Zone NP19/20 since this species occurs together with *Areosphaeridium michoudii*.

The age of the lower part of the Szymbark Shale (below the sample Fl7) is Late Eocene (Priabonian). This is shown by the co-occurrence of dinocyst species *Areosphaeridium diktyoplokum* (Fig. 4.11), *Areosphaeridium michoudii* (Fig. 4.10) and *Rhombodinium perforatum* (Fig. 4.24) in this interval (Fig. 6). The last appearance of *Areosphaeridium diktyoplokum*, which has the highest consistent occurrence in sample Fl7 (Fig. 6), was commonly believed to have taken place at the Eocene-Oligocene boundary (e.g. Biffi & Manum 1988; Stover et al. 1996), although some authors also found it in the Lower Oligocene (e.g. Maier 1959; Benedek 1986). Brinkhuis (1994) demonstrated the Early Oligocene last appearance of this species in Italy (for discussion see also Berggren et al. 1995 and Brinkhuis & Visscher 1995). *Areosphaeridium michoudii* has its highest known occurrence at the top of the NP18 Zone in the North Sea (Bujak & Mudge 1994). However, distribution of this species in the flysch Carpathians suggests its highest occurrence within the NP19-20 Zone (lower part of the Sub-Menilite Globigerina Marl; P. Gedl unpubl.). The highest consistent occurrence of *Areosphaeridium michoudii* in the studied section is recorded in sample Fl12, which is located higher than the highest consistent occurrence of *Areosphaeridium diktyoplokum* (sample Fl7). A Priabonian age of the lower part of the Szymbark Shale in the Folusz section is also indicated by the presence of *Rhombodinium perforatum*. This species

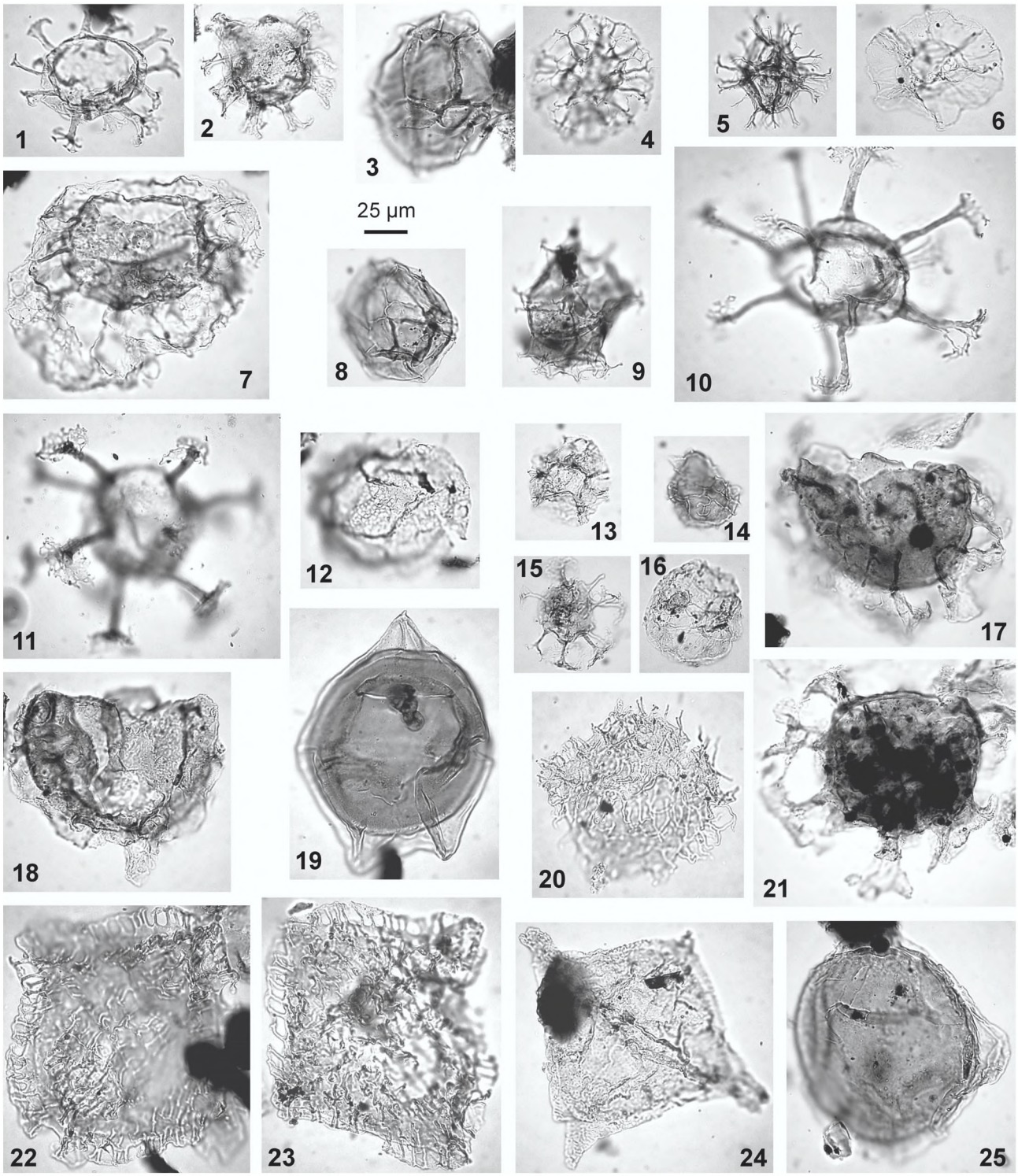


Fig. 4. Dinocysts from the studied section. Scale bar (25 µm) refers to all photomicrographs. Slide code and England Finder references are given. **1** — *Homotryblium plectilum*, Fl35a[H34.1]; **2** — *Areoligera*? *semicirculata*, Fl33b[E35.2]; **3** — *Impagidinium brevisulcatum*, Fl7[G47.4]; **4** — *Nematosphaeropsis labyrinthus*, Fl2b[J36.2–4]; **5** — *Spiniferites ramosus*, Fl33b[W46.2]; **6** — *Impagidinium velorum*, Fl2a[Q32.2]; **7** — *Glaphyrocysta semitecta*, Fl4a[U36.2]; **8** — *Impagidinium dispertitum*, Fl12a[R48]; **9** — *Rottnestia borussica*, Fl4a[T32.2]; **10** — *Areosphaeridium michoudii*, Fl2a[S45]; **11** — *Areosphaeridium diktyoplokum*, Fl2b[Q40.4]; **12** — *Heterelaucacysta porosa*, Fl4a[V43.1–3]; **13** — *Impagidinium pallidum*, Fl4a[X39.1]; **14** — *Corrudinium incompositum*, Fl12a[R39]; **15** — *Reticulatosphaera actinocoronata*, Fl12a[D47.2–4]; **16** — *Gelatia inflata*, Fl1[H37.2]; **17** — *Areoligera undulata*, Fl4a[N30.2]; **18** — *Membranophoridium aspinatum*, Fl4b[W31.1–3]; **19** — *Deflandrea* sp., Fl15b[F36]; **20** — *Wetzeliella gochtii*, Fl20b[C42]; **21** — *Areoligera sentosa*, Fl4b[X47.4]; **22** — *Charlesdowniea clathrata*, Fl4a[T34.1–2]; **23** — *Charlesdowniea coleothrypta*, Fl4b[H46.3]; **24** — *Rhombodinium perforatum*, Fl2b[W35.2–4]; **25** — *Dracodinium laszczynskii*, Fl1[G44.1–3].

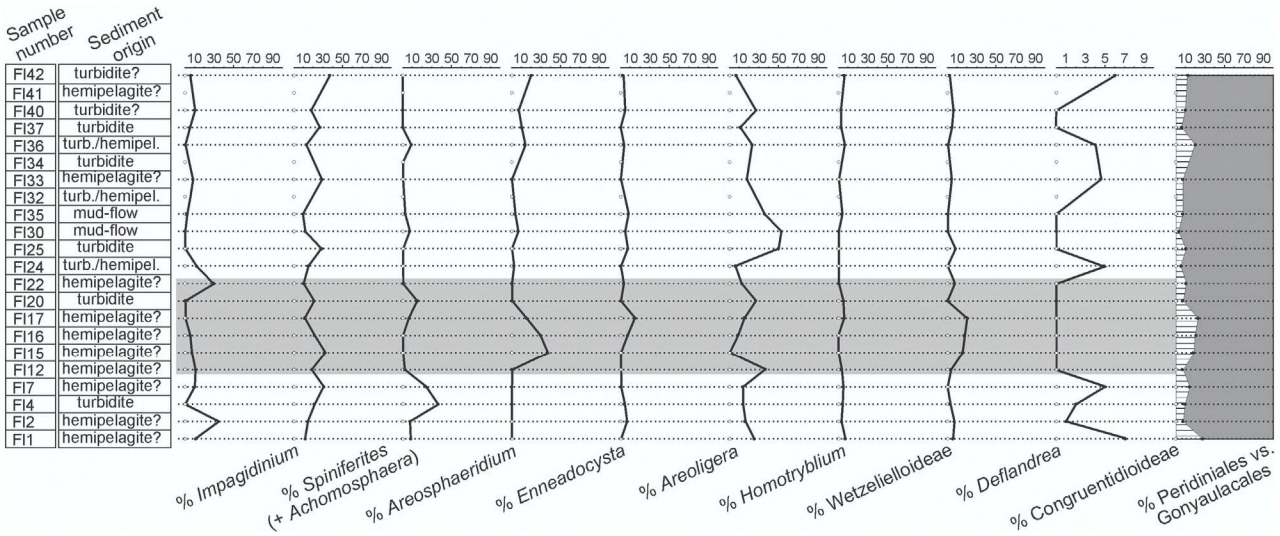


Fig. 5. Frequency of selected dinocysts in relation to sediment origin. Shadowed area shows undivided Upper Eocene-Lower Oligocene interval based on dinocysts.

has the lowest occurrence at the base of the NP18 Zone, and ranges to the end of the Eocene (Powell 1992). The age of the interval between sample Fl12 and Fl24 has not been precisely documented. It has been assigned as undivided latest Eocene-earliest Oligocene (Fig. 6).

Interpretation of age based on dinocysts agrees in general with that based on foraminifers (Malata *in* Leszczyński & Malata 2002) and calcareous nannoplankton (Oszczypko-Clowes 2001; Oszczypko-Clowes *in* Leszczyński & Malata 2002) for the lowermost part of the section (Fig. 7). All methods indicate a Late Eocene age of the basal part of the Szymbark Shale.

Significant differences appear in the biostratigraphy of the higher part of the section. Dinocysts indicate a Late Eocene

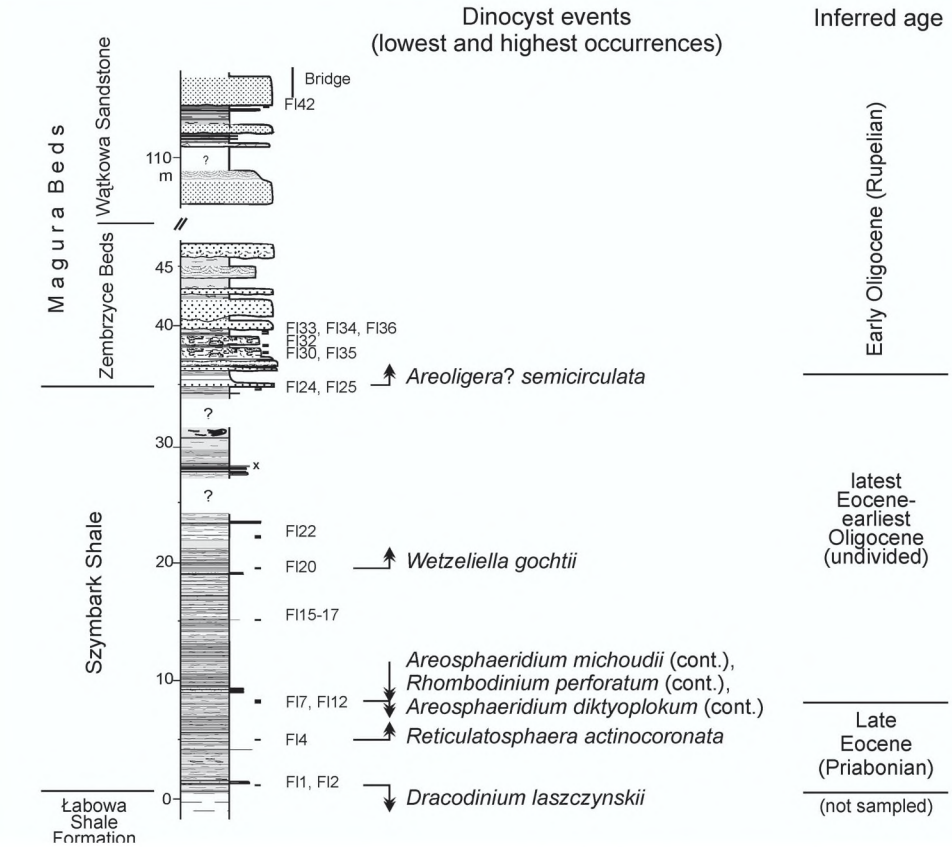


Fig. 6. Lowest and highest occurrences of selected dinocyst species in studied section and age interpretation.

age of the lower part of the Szymbark Shale up to the sample Fl7 (basal 8 meters of the section). Foraminifers interpreted by Malata (*in* Leszczyński & Malata 2002) indicate a Late Eocene age up to the sample Fl22. The assemblage from samples Fl18–Fl22 indicates an age close to the Eocene-Oligocene boundary. This means that the lowest occurrence of *Wetzeliella gochtii*, found in sample Fl20, is in the uppermost Eocene. Moreover, this implies that *Wetzeliella gochtii* in the Carpathian Flysch Basin appeared for the first time in the latest Eocene. Van Mourik & Brinkhuis (2000) noted a Late Eocene first appearance of this species from a low-latitude setting in the Atlantic Ocean. These records suggest diachronous first appearance of *Wetzeliella gochtii*, starting from low latitudes.

Calcareous nannoplankton, in turn, was interpreted by Oszczypko-Clowes (2001) to indicate the middle Priabonian, corresponding to the Zone NP19–20, for the ca. 11 m thick, basal part of the Szymbark Shale (i.e. approximately up to the position of our sample Fl12). Upper Priabonian to lower Rupelian, corresponding to the Zone NP21, was suggested there for the overlying part of the section, which according to the lithostratigraphy used in this paper, embraces the higher part of the Szymbark Shale and majority of the Zembrzyce Beds. Interpretations of calcareous nannoplankton by Oszczypko-Clowes (in Leszczyński & Malata 2002) suggest a middle Priabonian age for the Szymbark Shale up to the sample Fl18, found at least up to ca. 17 m above the lower boundary of the unit.

Dinocysts indicate the Lower Oligocene (Rupelian) in the section above sample Fl24. The age based on foraminifers from sample Fl24 was interpreted as undivided Priabonian-Rupelian. The lowest occurrence of Early Oligocene foraminifers was identified first in the sample Fl30 (mud-flow deposits containing a rich dinocyst assemblage interpreted as recycled Eocene). This sample is located in the lower part of the Zembrzyce Beds. A higher part of the lower Rupelian, corresponding to the Zone NP22, was identified with calcareous nannoplankton in the topmost part of the Zembrzyce Beds and in the remaining part of the section (Oszczypko-Clowes 2001; note: the position of the NP21 has been erroneously indicated there in fig. 44). Noteworthy, the chronostratigraphy of the succession in question as interpreted by Oszczypko-Clowes (2001) on the basis of calcareous nannoplankton data, suggests that nearly exclusively synsedimentary nannoplankton occurs in the resedimented deposits. This is difficult to comprehend, particularly in typical Magura Beds, which show features indicative of intensive, large-scale resedimentation.

Recycling of dinocysts

Recycling of dinocysts appears to have occurred in the studied sediments on a much larger scale than in coeval sediments in other parts of the flysch Carpathians. Pre-Eocene dinocysts are infrequent, represented mainly by single specimens. The oldest are Middle Jurassic species, represented by *Ctenido-*

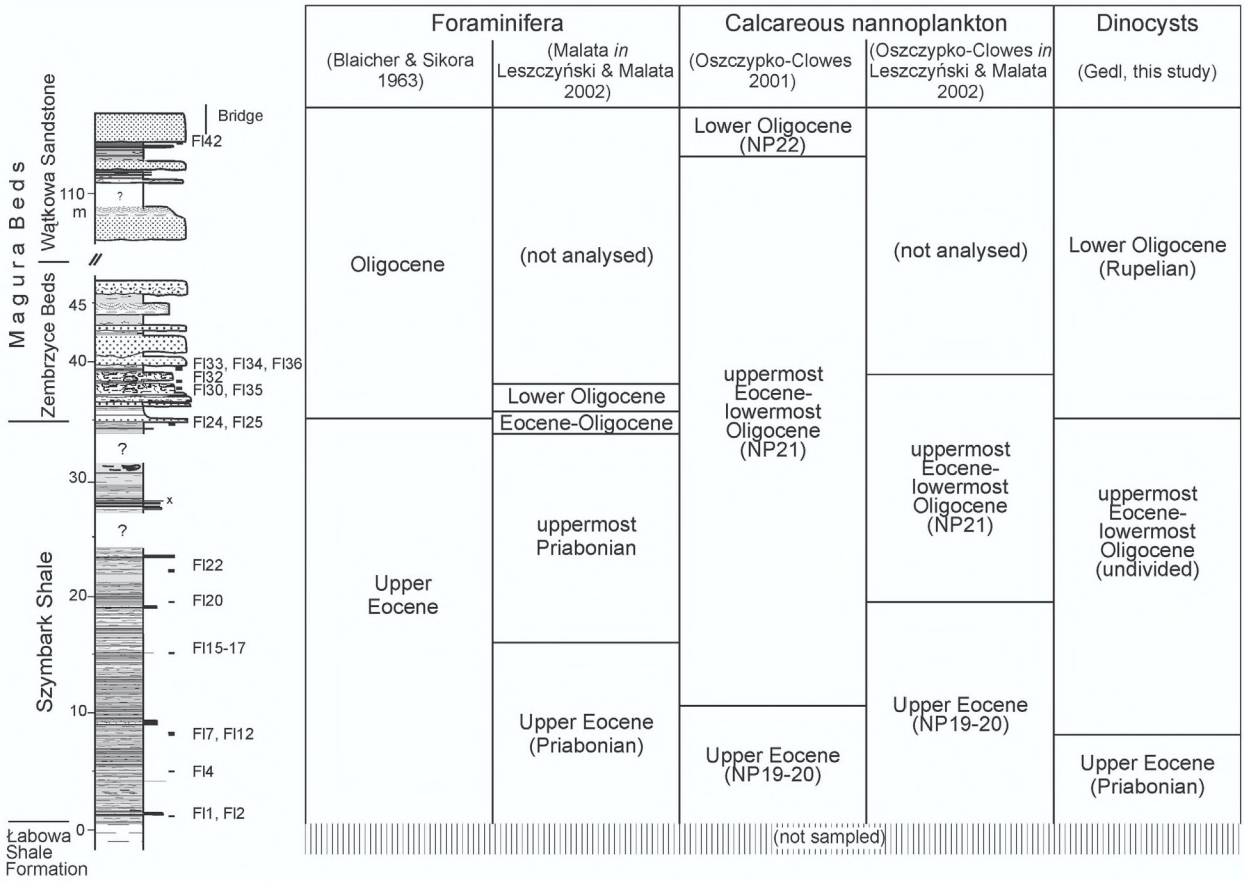


Fig. 7. Bio- and chronostratigraphic interpretation of studied section.

dinium ornatum-C. combazii, *Nannoceratopsis gracilis* and *Nannoceratopsis dictyambonis*. They were found in the lowermost part of the Szymbark Shale (samples Fl2 and Fl4) and in the Zembrzyce Beds (samples Fl32 and Fl37). One Early Cretaceous (*Pseudoceratium pelliferum*) and rare Late Cretaceous dinocysts (e.g. *Chatangiella ditissima*, *Trigonopyxidia ginella*) were found mainly in the Szymbark Shale. One specimen of Late Paleocene-Early Eocene *Apectodinium quinquelatum* was found in the Zembrzyce Beds (sample Fl37).

The Eocene taxa dominate among the dinocysts believed to be recycled. The most frequent are the Late Eocene species found in the Lower Oligocene part of the section. Mud-flow deposits (samples Fl30 and Fl35) and associated deposits (sample Fl36) exposed in the basal part of the Zembrzyce Beds contain numerous specimens of *Areosphaeridium michoudii*, *Areosphaeridium diktyoplokum* and *Cordosphaeridium funiculatum*. Their presence indicates that these deposits represent Upper or Middle Eocene sediments recycled during the Early Oligocene. Several Middle Eocene species were found in the Upper Eocene part of the section (e.g. *Diphyes pseudoficusoides*), while a single specimen of Early-Middle Eocene *Eatonicysta ursulea* was found in the Oligocene part of the Szymbark Shale.

There is no difference in the state of preservation between the forms treated as recycled or the *in situ* ones. That is why it is difficult to distinguish whether a given species with known early Late Eocene top-range (e.g. *Areosphaeridium michoudii*) is recycled or not in the higher part of the Upper Eocene of the studied section.

Paleoenvironment

The paleoenvironmental conditions in the northern part of the Magura Basin during the Late Eocene and Early Oligocene were reconstructed earlier mainly on the basis of lithofacies distribution and foraminiferal associations (e.g. Książkiewicz Ed. 1962; Sikora 1970; Bromowicz 1992; Leszczyński & Malata 2002). The shape of the basin, its bathymetry and bottom life conditions were the most essential in these interpretations. The palynological, and particularly dinocyst data presented in this paper, supply new information about paleoenvironmental conditions in this part of the Magura Basin.

A characteristic feature of the Eocene-Oligocene transition in the Polish Outer Carpathians is a significant change of the dinocyst assemblage. Diversified Late Eocene dinocyst assemblages disappeared during the earliest Oligocene or they were replaced by Peridinioid-dominated assemblages represented mainly by *Deflandrea* (Fig. 4.19) and *Wetzeliella* (Fig. 4.20). At the same time, a considerable increase of land-derived elements of palynofacies and amorphous organic matter is recorded (Gedl 1999). These changes have been recorded from several sections within the Silesian, Dukla and Skole tectonic units, and from a single section (Leluchów) within the southernmost zone of the Magura Nappe. The changes were interpreted as a result of eutrophication of the surface waters caused by fresh water influx into the Carpathian Flysch Basin (Gedl 1999) and appearance of disoxic/anoxic bottom conditions during sedimentation of the Early Oligocene Menilite Beds (or their equivalents).

The changes that took place during the Eocene-Oligocene transition in the northern part of the Magura Basin seem to differ from those in other parts of the Carpathian Flysch Basin. No such prominent change in the dinocyst assemblages, comparable to that known from coeval sediments of the other parts of the Outer Carpathians, was noted in the studied material. However, this may result from increased reworking, especially in the turbidites. A change in the quality of the dinocyst assemblages is recorded when hemipelagic samples exclusively are taken into account. Among the samples treated as hemipelagic Lower Oligocene sediments (Table 1), two (Fl32 and Fl41) are devoid of dinocysts or contain very infrequent ones. This may result from the appearance of paleoenvironmental conditions within the photic zone, which were inconvenient for dinoflagellates. Noteworthy, palynofacies implies land proximity of the sedimentary area.

Paleogeography: The location of the Siary Zone in marginal part of the Magura Nappe together with lithofacies distribution and paleocurrent directions were long ago interpreted as indicative of location of this zone close to the northern margin of the Magura Basin (e.g. Książkiewicz Ed. 1962). However, the presence of *Impagidinium* spp. in hemipelagites indicates an offshore setting of the sedimentary area of the studied deposits. The lack or infrequent occurrence of this genus in turbidites, where near-shore species prevail, indicates resedimentation of turbidites from inshore areas bordered by a landmass. Presence of a land on this side of the Magura Basin is suggested by the mass occurrence of land plant remains, which dominate the turbidite palynofacies. The domination of terrestrial elements (phytoclasts and sporomorphs) may result from a strong runoff, although scarcity of Peridiniales suggests no freshwater influx into this part of the Magura Basin (cf. e.g. Biffi & Grignani 1983). Phytoclasts and sporomorphs could also be recycled from older sediments as it is supported by the presence of recycled dinocysts, obviously derived from older sediments.

A ridge, suggested by Książkiewicz (1956), called the Silesian cordillera (Fig. 8), is generally accepted as the northern border of the Magura Basin. It remains an open question whether it was a land or a submerged ridge. Nemčok et al. (2000) proposed a different paleogeographical setting for the Magura Basin, with the Bohemian Massif as its northern border. The palynological analysis does not solve the question whether the Bohemian Massif or Silesian cordillera was the northern margin of the Magura Basin, but in the latter case, at least some parts of this ridge, at least for some time, must have formed islands covered by vegetation.

A different paleogeographic location is identified for the southernmost part of the Magura Basin during the Late Eocene-Early Oligocene. Late Eocene dinocysts (numerous *Impagidinium* and *Nematosphaeropsis* spp.; see Dale 1996) from coeval deposits at Leluchów (Krynica Zone) imply a depositional setting located far from the seashore (Gedl 2004). The change in the Leluchów dinocyst assemblages and palynofacies close to the Eocene-Oligocene boundary (established on the basis of the highest occurrence of *Areosphaeridium diktyoplokum*) is similar to that known from the outer nappes of the Carpathians. The low-salinity dinocysts (mainly *Deflandrea* spp.) dominate in the lowermost Oligocene of Le-

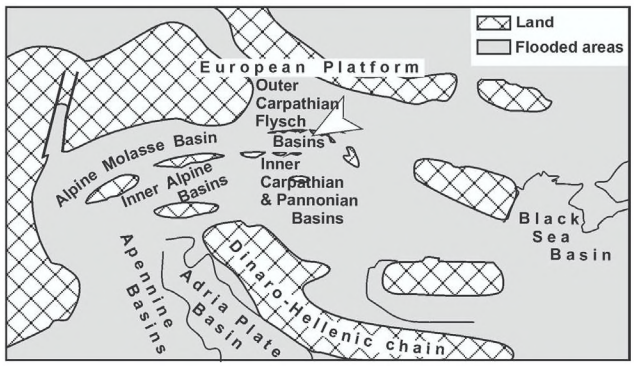


Fig. 8. Schematic paleogeographic map of Alpine and peri-Alpine part of Europe during Eocene-Oligocene transition (based on Rögl 1999, modified by S. Leszczyński). Probable location of investigated section arrowed.

luchów, and disappear higher up the section. These conclusions imply major regional differences between northern and southern margins of the Magura Basin during the Late Eocene and Early Oligocene.

Sea surface temperature: Dinoflagellates, that is inhabitants of the photic zone, as well as their cysts serve as a tenable indicator of the sea surface temperature. The Eocene-Oligocene transition is known as a time of marked global cooling (e.g. Pomerol & Premoli Silva 1986). Brinkhuis (1994), who traced the records of high latitude dinocyst species within the Eocene-Oligocene boundary interval in Mediterranean, recognized sea surface temperature fluctuations. For this reason he used several, both inshore and offshore species, whereas Zevenboom (1995) argued that only oceanic taxa are suitable for proper estimation of the sea surface temperature. Three species of oceanic dinocysts found in the Folusz section are treated as high latitude ones. These are *Impagidinium velorum* (Fig. 4.6), *Impagidinium pallidum* (Fig. 4.13) and *Gelatia inflata* (Fig. 4.16) described for the first time by Bujak (1984) from the Bering Sea. These species have been found in the lower part of the Szymbark Shale. Their presence may reflect a cooling phase in the Late Eocene, which caused a drop in sea surface temperature during sedimentation of the lower part of the Szymbark Shale. This event seems to correspond to that documented in coeval sediments of the other parts of the Carpathians where high latitude dinocysts *Impagidinium velorum*, *Impagidinium pallidum* and *Gelatia inflata* have been found as well (Gedl unpubl.).

Bottom water oxygenation: Analysis of trace-fossil and benthic foraminiferal assemblages from the Siary Zone indicate poorly oxic to slightly dysoxic conditions prevailing in the bottom waters during the Late Eocene and Early Oligocene (Leszczyński & Malata 2002). This interpretation is supported by the results of our study. The studied sediments contain only occasional traces of amorphous organic matter, which is usually associated with anoxic environments (e.g. Batten 1996). This feature highly contrasts with high content of amorphous organic matter in the Lower Oligocene Menilite Beds and its equivalents in the other parts of the flysch Carpathians (Gedl unpubl.). A better ventilation of the sea floor in the northern part of the Magura Basin during the Early Oligocene might have been caused by intensified water circulation resulting from a high frequency of large-scale resedimentation events (Leszczyński 2001).

Conclusions

1. Dinocysts indicate that the lower part of the Szymbark Shale in the Folusz section (up to the sample Fl7) represents the Upper Eocene (Priabonian). This interpretation is based on continuous presence of *Areosphaeridium michoudii*, *Areosphaeridium diktyoplokum* and *Rhombodinium perforatum*. Several species characteristic for the Middle Eocene (e.g. *Heterelaucacysta porosa*, *Diphyes pseudoficusoides*) that occur in this part of the section are recycled. The uppermost part of the Szymbark Shale, located above the sample Fl24, and the overlying Magura Beds represent the Lower Oligocene. This interpretation is based on the lowest occurrence of *Areoligera*? *semicirculata* in the sample Fl24. *Wetzeliella gochtii*, a typical Oligocene species in north-western Europe, has the lowest occurrence in the studied section in sample Fl20, dated by foraminifers as Priabonian. Another Oligocene species, *Reticulatosphaera actinocoronata*, has its lowest occurrence in the basal part of the section, dated by other dinocysts, foraminifers and calcareous nannoplankton as Priabonian.

2. Two dinocyst assemblages differing in origin occur in the fine-grained sediments of the entire section. Sediments recognized as redeposited contain frequent near-shore dinocysts. In contrast, the fine-grained sediments interpreted as background deposits always contain specimens of oceanic dinocyst genus *Impagidinium*.

3. No apparent change in quality of dinocyst assemblages is observed in the studied section between the Late Eocene and Early Oligocene assemblages. This contrasts with substantial changes in dinocyst assemblages in coeval sediments of the other parts of the Polish Carpathians. This difference implies various paleoenvironmental conditions, including nutrient availability and salinity level in the photic zone of the northern part of the Magura Basin. However, increased dinocyst recycling observed in the Folusz section may significantly mask the true conditions. Two Lower Oligocene hemipelagic samples containing poor dinocyst assemblages appear to reflect inconvenient paleoenvironmental conditions in the photic zone.

4. The appearance of high-latitude *Impagidinium velorum*, *Impagidinium pallidum* and *Gelatia inflata* in the Upper Eocene of the investigated deposits is interpreted as resulting from a drop of sea surface temperature in the Magura Basin during the latest Eocene. This event, which is also recorded in coeval sediments of the other parts of the Polish Carpathians, seems to be of regional significance and appear to correspond to the global cooling recorded across the Eocene-Oligocene boundary.

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